Accounting Rules for CO_2 Capture and Storage

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A Research Project on
Accounting Rules on CO_2 Sequestration for Creation of National GHG Inventories (ARCS)

Contents

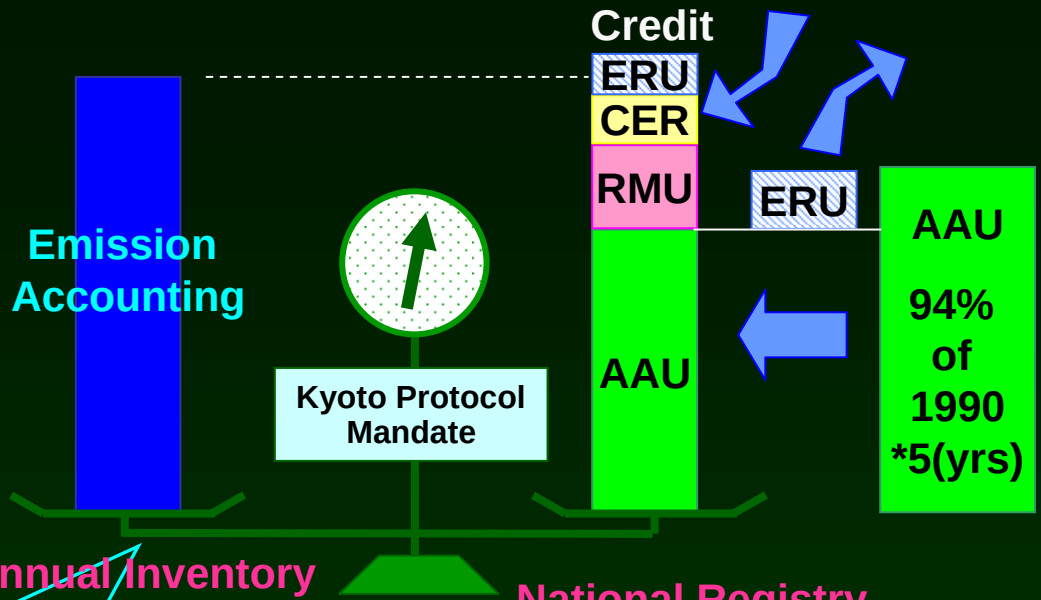
(1) Background

Related issues surrounding CCS technologies

- Lack of recognition as vital mitigating options among policy makers and public
- Uncertainties regarding the validity of the technologies:
  - Interpretation under UNFCCC and/or Kyoto Protocol
  - Methodology of accounting reductions by CO_2 sequestration technologies under IPCC Guidelines for National Greenhouse Gas Inventories and reflecting them into "National Communications"

(1) Background

National GHG Inventories and Kyoto Protocol



- IPCC Guidelines for National Greenhouse Gas Inventories
- Revised1996 IPCC Guidelines for National Greenhouse Gas Inventories
- Good practice Guidance (TSU, 2000)
- Good Practice Guidance for LULUCF (TSU, 2003)
- Decision by COP/MOP

IPCC Special Report on LULUCF

IPCC Special Report on CCS

(2) Framework
Scope of ARCS project

- **To develop models** to assess effectiveness of storage and conduct case studies for various CO_2 injection scenarios
- **To propose guideline and/or protocol** for accounting sequestered CO_2 into GHG emission inventories through "thought experiment" using developed models

- **To assess socio-economic and policy implications** of the technology through energy modeling and evaluation of business opportunities

(2) Framework

Emission Estimation Methodology

IPCC Framework
✓ Scientific assessment

UNFCCC Framework
✓ Workable rules

Accounting Rules for National Inventories

Accounting Rules for Project-based Activities

(3) Key Factors and Approach

(i) Non permanency → needs estimation of leakage

- Injected CO_2 has possibility to leak from the storage reservoir and return to the atmosphere in a long term = **non-permanency of storage.**
- Necessity to **evaluate net emission reduction amount** by the CCS technology taking leakage and sudden release into account.
- Geological and ocean storages have different characteristics.

(3) Key Factors and Approach

Characteristics of ocean and geological storage

	Geological Storage	Ocean Storage
Concept	• Sealed against atmosphere (varies with the type of technology or geological structure)	• An open structure against atmosphere. (A role to accelerate the interaction of ocean and atmosphere.)
Years of storage	• High site dependency • CO_2 will be stored over thousands of years.	• Not enough information on years of storage yet. • CO_2 will be stored over hundreds of years.
Control factors	• Soundness of sealing structure • Depth (pressure, temperature), permeability, etc.?	• Geographical area and depth of injection
Monitoring for evaluation	• The monitoring technology for geological CO_2 behavior and seepage is being developed • Spatial and time range of monitoring are addressed.	• The actual long-term monitoring is almost impossible. • The leakage rate estimation by the model will become a basis.
Sudden release	• There is a possibility.	• The possibility is low (excluding below sea bottom storage).

(3) Key Factors and Approach

(ii) Timeframe

- Timeframe related to reduction timing → full credit given initially
  - Concern about damage due to climate change.
  - Marginal damage of climate change over time depends on level of temperature, rate of temperature change and socio-economic condition.
  - High uncertainty of far future damages and needs to mitigate rapid near-term climate change.

    → a few hundred years ?
- Timeframe related to risk of leakage → discount, compensation
  - Concern about risk of long term leakage.

    → a few thousand - hundreds of thousand years ?
- Timeframe related to institutional approach → rule applicable for a realistic period
  - Rules covering very long-term based on the assumption of continued existence of present structure of international society are unrealistic.

- Considerations and definitions on timeframe is crucial to promote the use of "mechanism."
- We need more discussion to resolve the issue.

(3) Key Factors and Approach

(iii) International acceptability

- When refer to the past arguments about LULUCF, it is clear that the so called process of political negotiations greatly influence rule making.
- Agreeable rules needed for CCS
  - → Simple and clear rules
  - → Conservativeness to account effects of CCS

(3) Key Factors and Approach

Consideration on the factors for rule making

	CO_2 emission reduction accounting methodology	Accounting rules for National Inventories	Accounting rules for project based activities
(i) Non-permanence of storage	Important	Important	Important
(ii) Timeframe	Unconsidered	Considered	Important
(iii) Possibility of international agreement	Considered	Considered	Considered

(4) Emission Estimation Methodology

Net storage amount of CCS technology

Net CO_2 stored (emission avoided)

$$= E_{cap} - (AdE_{cap} + AdE_{trans} + AdE_{inj}) - (LkE_{cap}, + LkE_{trans}, + LkE_{inj}) - (SP_{store}) - (Sd_{store})$$

Symbol	Explanation	Coverage by existing guideline	Identification of amount in yearly base
E_{cap}	Amount of CO_2 from source	✓	
AdE_{cap}, AdE_{trans}, AdE_{inj}	Amount of CO_2 released by energy use (in capture /transportation /injection processes)	✓	Possible
LkE_{cap}, LkE_{trans}, LkE_{inj}	Amount of CO_2 leakage (in capture /transportation /injection processes)	✓	Possible
SP_{store}	Amount of CO_2 leakage to atmosphere from storage reservoir in a long term	–	Development of Methodology is needed
Sd_{store}	Amount of accidentally released CO_2 to atmosphere from storage reservoir	–	Development of Methodology is needed

(4) Emission Estimation Methodology

Estimation of amount of CO_2 leakage in a long term

- **3 Levels:**
  - Select according to availability of relevant science and technology.

Level	Concept	When apply?	Accuracy	Cost
1	• Simple estimation without detailed evaluation of reservoir. • The amount of leakage is calculated using leak coefficient or simple equation. • The resulted values are conservative inevitably.	• Detailed simulation technologies and physical parameters are not available.	Low	Low
2	• Estimation considering the site specificity in detail. • The amount of leakage are calculated by simulation based on the guideline.	• Physical and chemical data is available.	Medium	Medium
3	• Measuring of the yearly amount of leakage. • Continuous monitoring is required.	• High level technology is available.	High	High

(4) Emission Estimation Methodology

Level 1 Method (Ocean-1)

- **Concept**
  - Leak Curve : depends on point & depth
  - Complicated Mechanism : atmosphere-ocean interaction, diffusion, biological process etc.
  - Simulation by ARCS original evaluation model "DONGRI"
    - Characteristics
      - atmosphere-ocean interaction, vertical & horizontal diffusion、biological pump

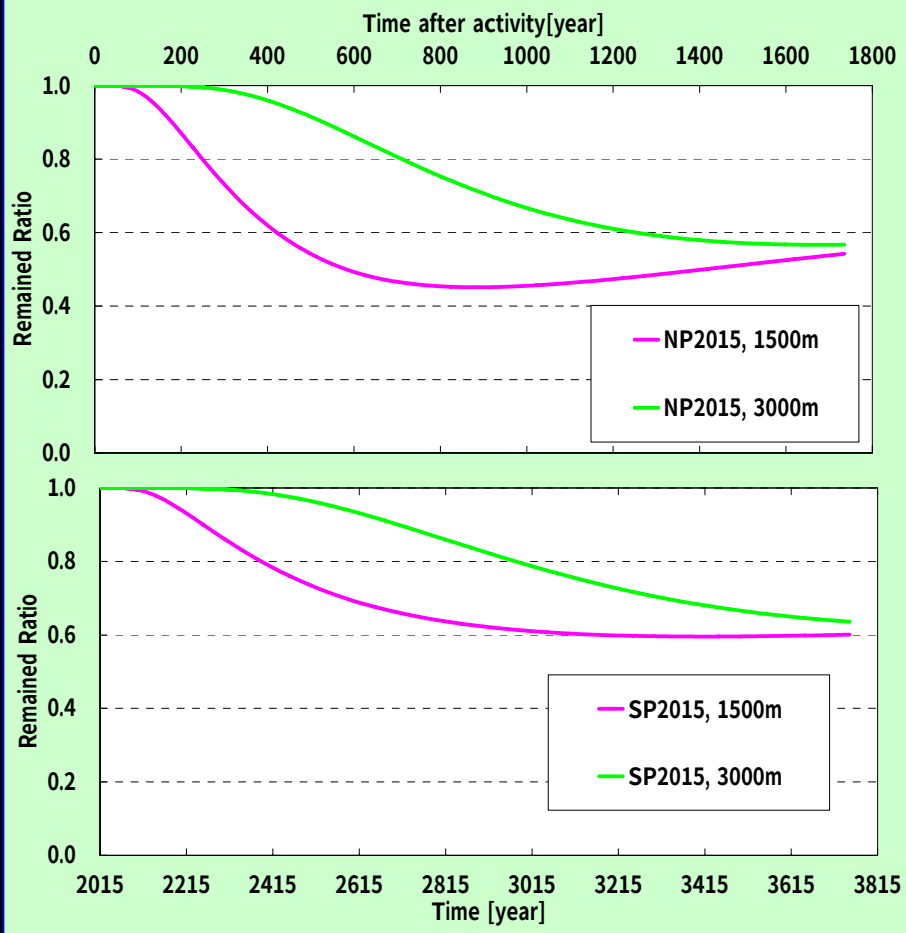
Definition of Leak Rate (*t*):

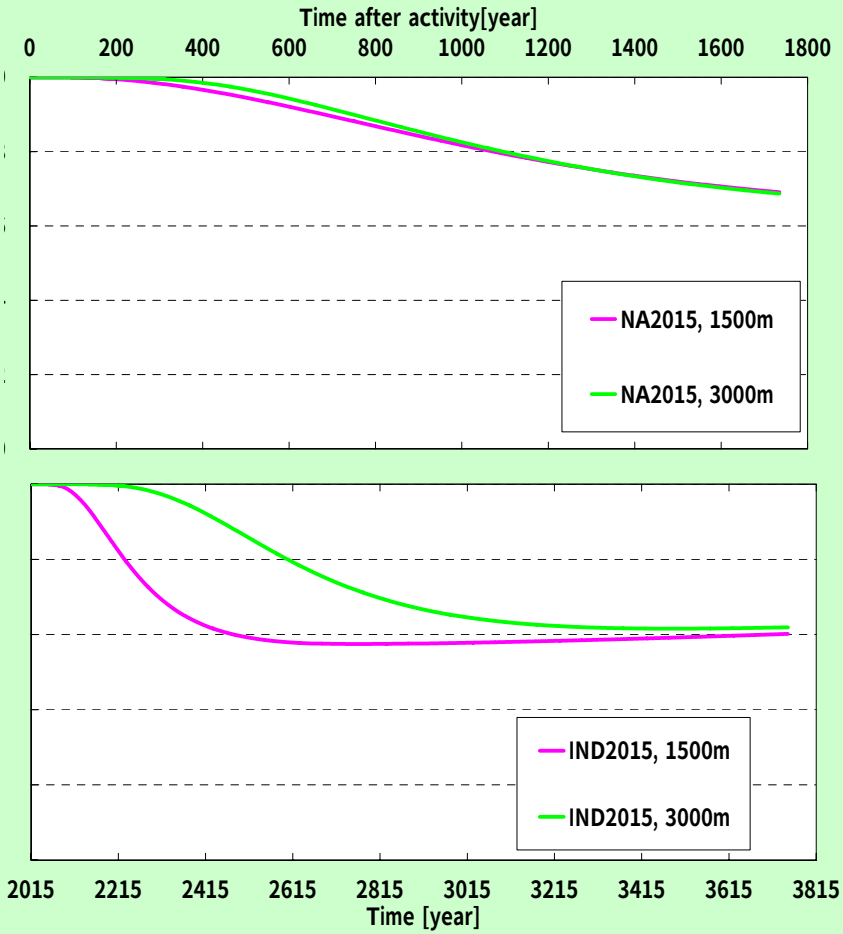
$$\text{Leak Rate}(t) = \frac{[\text{Amount of } CO_2 \text{ leaked to atmosphere from storage}]}{[\text{Amount of stored } CO_2]}$$

$$= \frac{[\text{Amount of } CO_2 \text{ in the atmosphere at time } t \text{ in case of complete sequestration (no leak)}] - [\text{Amount of } CO_2 \text{ in the atmosphere at time } t \text{ in case of ocean sequestration}]}{[\text{Amount of stored } CO_2]}$$

(4) Emission Estimation Methodology

Level 1 Method (Ocean-2)





(4) Emission Estimation Methodology

Level 1 Method (Ocean-3)

Ocean	Depth	Period of 100%	Leak Rate (%) (applied year period)		Final Amount
North Pacific	Mid	0 - 70	0.15 (70 - 400)	0.02 (400 - 800)	42.5% at 800
	Deep	0 - 200	0.05 (200 - 1000)	0.01 (1000 - 1400)	56.0% at 1400
South Pacific	Mid	0 - 70	0.08 (70 - 500)	0.015 (500 - 1000)	58.1% at 1000
	Deep	0 - 200	0.03 (200 - 1200)	0.015 (1200 - 1800)	61.0% at 1800
North Atlantic	Mid	0 - 70	0.02 (70 - 1400)	0.015 (1400 - 1800)	67.4% at 1800
	Deep	0 - 200	0.022 (200 - 1400)	0.015 (1400 - 1800)	67.6% at 1800
South Atlantic	Mid	0 - 70	0.025 (70 - 1000)	0.015 (1000 - 1800)	64.8% at 1800
	Deep	0 - 200	0.025 (200 - 1200)	0.015 (1200 - 1800)	66.0% at 1800
Indian	Mid	0 - 70	0.15 (70 - 300)	0.03 (300 - 600)	56.5% at 600
	Deep	0 - 200	0.06 (200 - 700)	0.02 (700 - 1200)	60.0% at 1200
Arctic	Mid	0 - 150	0.022 (150 - 1400)	0.01 (1400 - 1800)	68.5% at 1800
	Deep	–	–	–	–
Southern Sea (P)	Mid	0 - 70	0.03 (70 - 1000)	0.01 (1000 - 1800)	64.1% at 1800
	Deep	0 - 200	0.025 (200 - 1400)	0.01 (1400 - 1800)	66.0% at 1800
Southern Sea (A)	Mid	0 - 50	0.04 (50 - 600)	0.015 (600 - 1500)	64.5% at 1500
	Deep	0 - 200	0.028 (200 - 1200)	0.012 (1200 - 1800)	64.8% at 1800
Southern Sea (I)	Mid	0 - 70	0.03 (70 - 1200)	0.01 (1000 - 1800)	64.1% at 1800
	Deep	0 - 200	0.028 (200 - 1200)	0.012 (1200 - 1800)	64.8% at 1800

(4) Emission Estimation Methodology
Level 1 Method (Geological-1)

- **Concepts**
  - High site dependency → **Simple evaluation equation**
  - Count all CO_2 released from reservoir (**leakage**) ≠The amount of CO_2 release to the atmosphere → **but clearly conservative**
  - Does **not consider the final fixed** amount besides coal seam.
  - Represent all possible leak paths as "**seal permeability**".

Simple Evaluation Equation

$$CQF = \frac{H}{\kappa}, \quad \kappa = \frac{k^{effective}\Delta\rho g}{\eta},$$

$$k^{effective} = k^{mat} + k^{frac} + k^{well}$$

CQF： Cap rock Quality Factor (sec)
H： Cap rock height
κ： CO_2 conductivity (m/sec)
$k^{effective}$： Effective permeability (m^2)
η^{CO2}： Effective viscosity of CO_2 in the media (Pa·sec)
$\Delta\rho g=(\rho^{water}-\rho^{CO2})g$： relative gravity of CO_2 (N/m^3)
k^{mat}：matrix permeability measured with core samples (m^2)
k^{frac}：fault and fracture permeability (m^2)
k^{well}：equivalent permeability of abandoned boreholes (m^2)

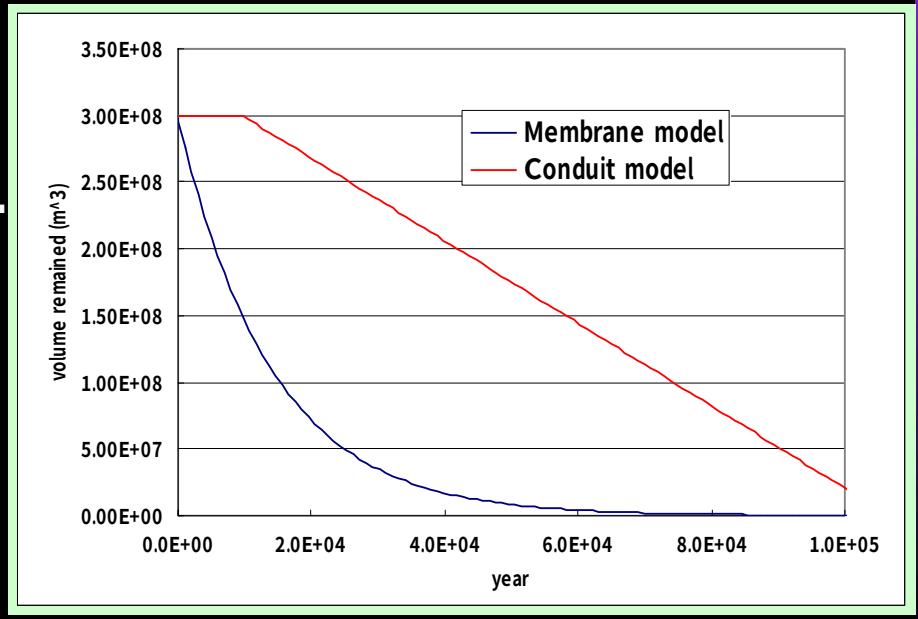
(4) Emission Estimation Methodology
Level 1 Method (Geological-2)

Conduit Model

- Applicable when soundness of cap rock is guaranteed like in oil/gas field or reliable parameters of cap rock quality are available. The basic ideas are:
  - Conduits exist to pass CO_2 molecules to cap rock.
  - CO_2 molecules passes cap rock at a certain speed and CQF is necessary length of time for stored CO_2 to reach the top of cap rock.

Membrane Model

- Applicable when the seal is imperfect or low reliability for data such as matrix permeability.
- The basic ideas are:
  - CO_2 molecules randomly pass through cap rock and CQF is an average speed to pass through cap rock.
  - The cap rock is permeability, a membrane without thickness and CO_2 molecules continuously pass through it at a constant ratio.



(4) Emission Estimation Methodology

Level 1 Method (Geological-3)

<table>
<tr><th>Category</th><th>Leak rate</th><th>Sample value of leakage (%)</th></tr>
<tr><td colspan="2">Certain structural seal
(oil field gas field)</td><td>Expressed in Conduit Model

Leak Rate:
Time 0~CQF : $V_{leak} = 0$
Time $_{CQF \sim CQF + \frac{Vinj}{k \cdot A}}$: $V_{leak} = \frac{kA}{V_{injected}}$
Time $_{CQF + \frac{Vinj}{k \cdot A} \sim}$: $V_{leak} = 0$
CQF: 10^3 ~ 10^6</td><td>
<table>
<tr><th></th><th colspan="3">Condition</th></tr>
<tr><th>year</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>0</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>10</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>100</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>200</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>500</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>1000</td><td>0.0</td><td>0.0</td><td>5.4E-2</td></tr>
<tr><td>2000</td><td>2.1E-2</td><td>0.0</td><td>5.4E-2</td></tr>
<tr><td>5000</td><td>2.1E-2</td><td>8.8E-3</td><td>0.0</td></tr>
</table>
</td></tr>
<tr><td colspan="2">Uncertain seal
(some aquifers)</td><td rowspan="2">Expressed in Membrane Model

CQF: 10^2 ~ 10^3</td><td rowspan="2">
<table>
<tr><th></th><th colspan="3">Condition</th></tr>
<tr><th>year</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>0</td><td>6.3E-2</td><td>2.7E-2</td><td>1.6E-1</td></tr>
<tr><td>10</td><td>6.3E-2</td><td>2.7E-2</td><td>1.6E-1</td></tr>
<tr><td>100</td><td>5.9E-2</td><td>2.6E-2</td><td>1.4E-1</td></tr>
<tr><td>200</td><td>5.6E-2</td><td>2.5E-2</td><td>1.2E-1</td></tr>
<tr><td>500</td><td>4.6E-2</td><td>2.3E-2</td><td>7.2E-2</td></tr>
<tr><td>1000</td><td>3.4E-2</td><td>2.0E-2</td><td>3.2E-2</td></tr>
<tr><td>2000</td><td>1.8E-2</td><td>1.6E-2</td><td>6.5E-3</td></tr>
<tr><td>5000</td><td>2.7E-3</td><td>7.0E-3</td><td>5.2E-5</td></tr>
</table>
</td></tr>
<tr><td rowspan="2">No effective seal</td><td>Aquifer without cap rock</td></tr>
<tr><td>Coal fields</td><td>to be determined</td><td></td></tr>
</table>

A:1000m deep k=2.01E-9m/sec (CQF=1580years) B: 2000m deep k=8.41 E-10m/sec (CQF=3770years)
C: 500m deep k=5.09 E-9m/sec (CQF=622years) Area of CCS layer A=1km^2

(5) Accounting Rules for National Inventories

Inventory system options

- **Option 1**
  - **Not specifying amounts of stored CO_2 by CCS and treat them as avoided emission**
- **Option 2**
  - **Specifying amounts of stored CO_2 by CCS and introduce of new units**
    - Sink such as forest removes CO_2 from atmosphere (removal by sink) and the amount is treated as RMU (Removal Unit).
    - Although CCS does not remove CO_2 from atmosphere, the similar approach might be applied.

(5) Accounting Rules for National Inventories

Accounting rule options for avoided emission

Proposal	Accounting for avoided emission	Advantage/ Disadvantage	Considerations
	Count whole injected amount	• Simple • Overestimate effect of CCS	• Unacceptable?
X	Count whole injected amount initially then leakage to be accounted as emission yearly	• Reflecting the nature of CCS • Rather complicated	• Endless rule ? • Increase of transaction costs → resolved using 3 level methodology
	Discount (technology specific, site specific)	• Simple • Difficult to define appropriate discount rate	• Uniform rate discourage incentive for implementation

(5) Accounting Rules for National Inventories

- **Proposed option**
  - **Avoided Emission = Emission successfully injected per year by the CCS activity**
    - Energy penalty + Leakage in the process: counted according to IPCC Guideline
  - **Long-term leakage = yearly emission**
    - 3 Level Methodology available
  - **Sudden Release = accounted when it happened**

(6) Accounting Rules for Project-based Activities

- Kyoto Mechanism
  - Applied only to the first commitment period
  - CCS has little opportunity in the first commitment period
- Issues on accounting rules under Kyoto Mechanism and expected future Mechanism(s)
  - (1) Permanent or Temporary?
  - (2) How to treat leakage?
  - (3) Cap is needed?

(6) Accounting Rules for Project-based Activities

Proposals [e.g.]	Option	Advantage	Disadvantage
	Discount & permanent	High transferability	Difficult to find appropriate discount rate
	Credit Ton-year	High transferability	Low incentive initially.
X [1] [2]	Temporary	Transferable	Low credit value (liability for full compensation)
X [3] [4]	Credited all initially then leakage to be compensated* by certain interval	Reflecting the nature of CCS	Long liability Low transferability?

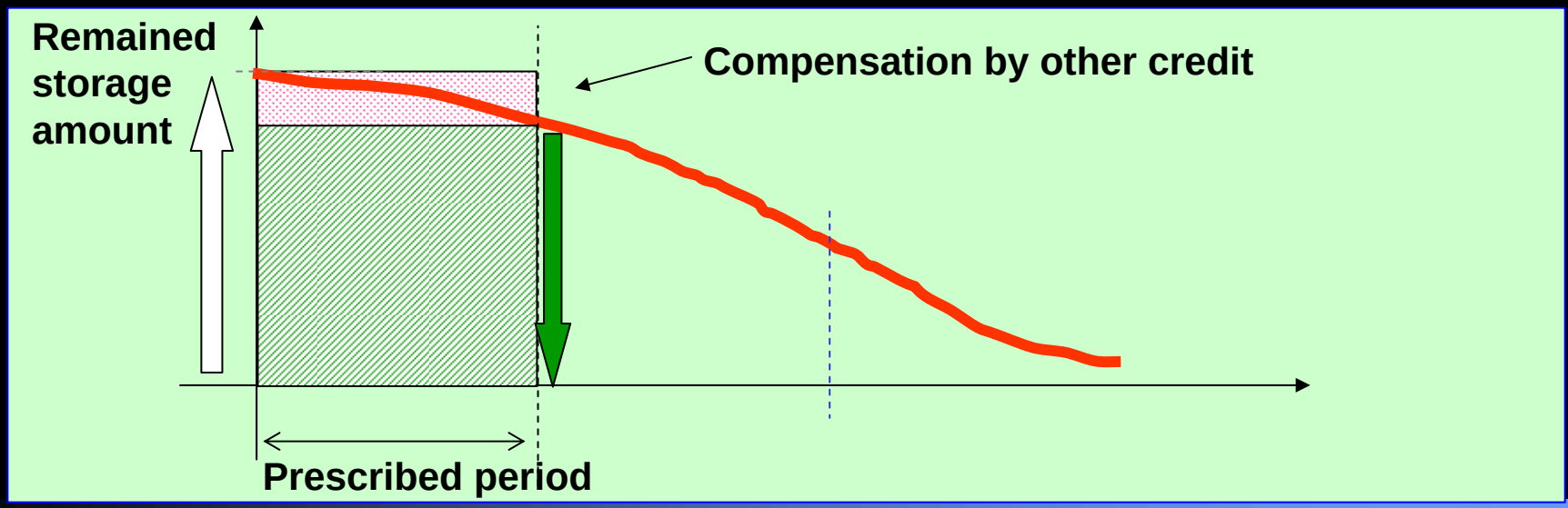
*Leakage can be compensated by a transferable debit

(6) Accounting Rules for Project-based Activities

Several options

[1] Credit is given to the **whole amount** stored, but the whole amount should be compensated by other credit after a certain period (ex. 100 years).

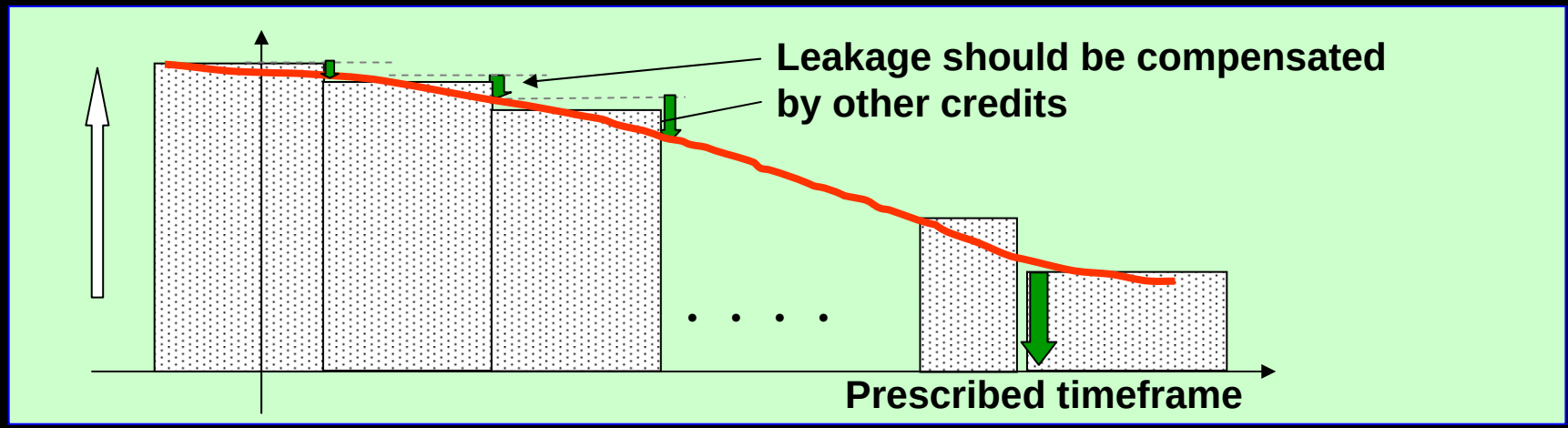
[2] Credit is give to the **estimated storage amount after a certain period** (ex. 100 years), but the whole amount should be compensated by other credit after a certain period.



(6) Accounting Rules for Project-based Activities

[3] Credit is given to the whole amount stored, but the leakage should be checked after a certain period (ex. 30 years) and compensated by other credit. After a prescribed timeframe (ex. 300 years), the **remaining amount should be compensated by other credit**.

[4] Credit is given to the whole amount stored, but the leakage should be checked after a certain period (ex. 30 years) and compensated by other credit. After a prescribed timeframe (ex. 300 years), the **remaining amount should be considered as permanent sequestration**.



- When the credit was consumed within the commitment period, the duty to compensate should be remained through the end of the prescribed timeframe.

Summary

- **Proposal of leakage estimation and accounting rules for CCS**
- **Estimation of avoided emission**
  - **Net amount of avoided emission should be estimated.**
  - **3 Level methodologies are presented.**
- **Accounting rules for National Inventories**
  - **We propose that successfully stored CO_2 is accounted as avoided emission initially.**
  - **The leakage can be accounted yearly.**
- **Accounting rules for project-based activities**
  - **Temporary crediting can be one of the solutions to promote credit transfer.**

A draft accounting rule for CCS ver2.3 will be available soon.

Thanks to the Useful Discussions:

- Howard Herzog (MIT)
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- Riitta Pipatti (TSU, IPCC NGGIP)

and

- ARCS project members

Thank you !

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